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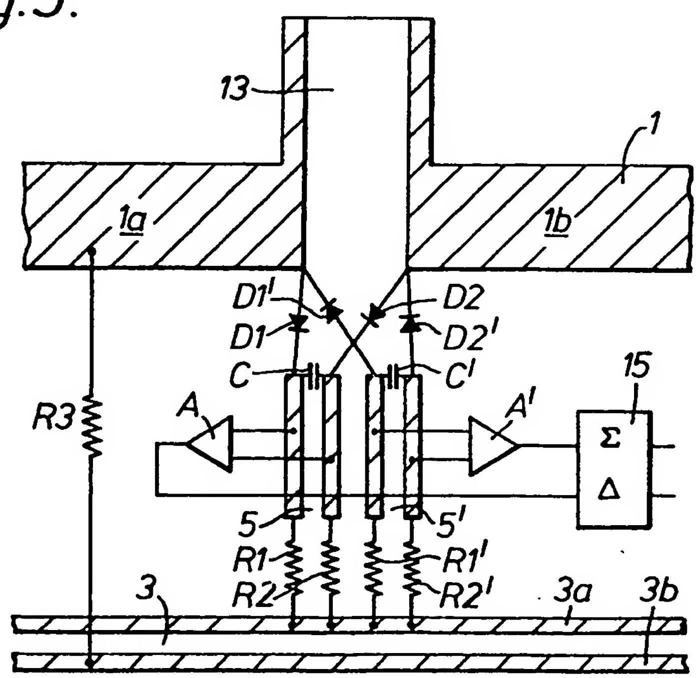
UK CL (Edition E) H1Q

(54) Harmonic mixer and circuit

(57) At least one diode D_1, D_2 etc is positioned between the limbs 1a,1b of a planar dipole antenna 1, all assembled at the surface of a high resistivity body (7, Fig 1). A signal of intermediate frequency f_I, a frequency given by the difference in frequency of signal radiation f_s and an harmonic nf_R of a reference signal supplied from a local oscillator LO through conductors 3a, 3b, directly coupled to the mixer, is extracted by means of a narrow band amplifier A connected to the mixer. The mixer comprises one diode D, two diodes D1, D2, or, in preference to these, a ring of four diodes D1,..,D2'. The body (7) may be of semiconductor material and the diodes incorporated as components integrated with the semiconductor material. The harmonic mixer circuits may be utilised alone, or with other like circuits in array, using a common substrate (7), feed lines 3, and reference source LO. Several arrays (M1,M2, M3) Fig 15 may be combined with a dielectric lens 21 and component mirrors 25, 27.

Fig.5.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig.1.

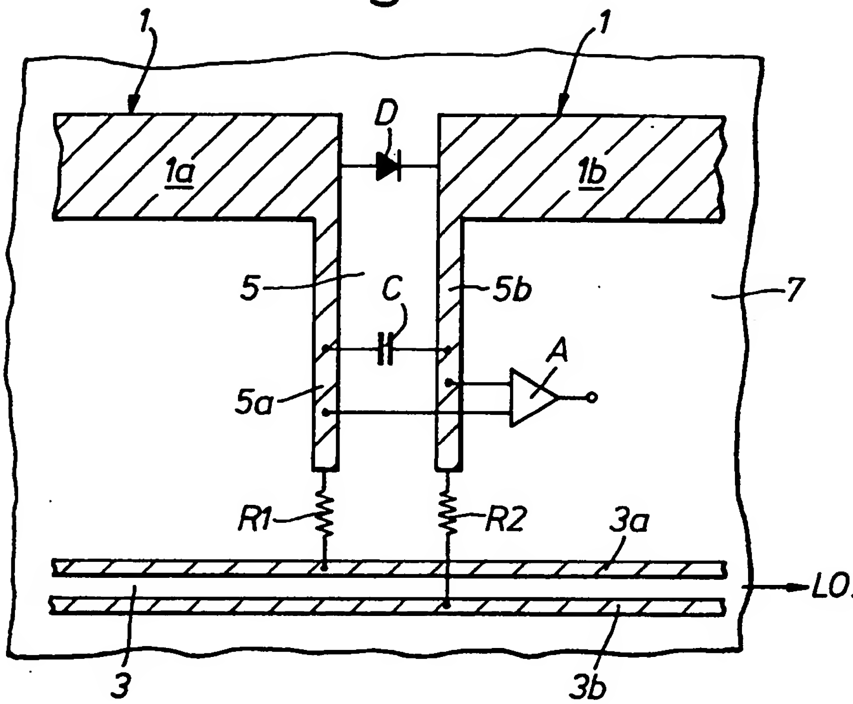


Fig.2.

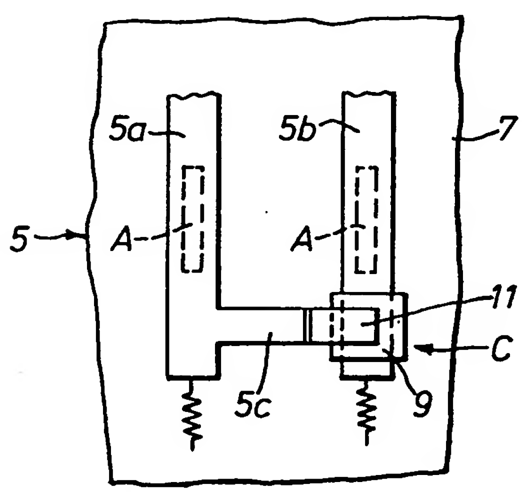


Fig. 3.

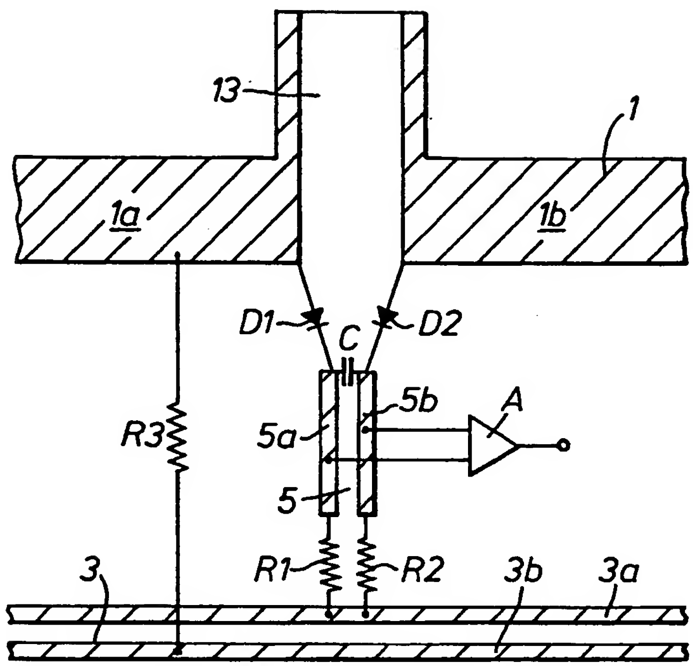

13
1
1a
1b
D1
C
D2
5b
A
R3
5a
5
R1
R2
3
3b
3a

Fig. 4.

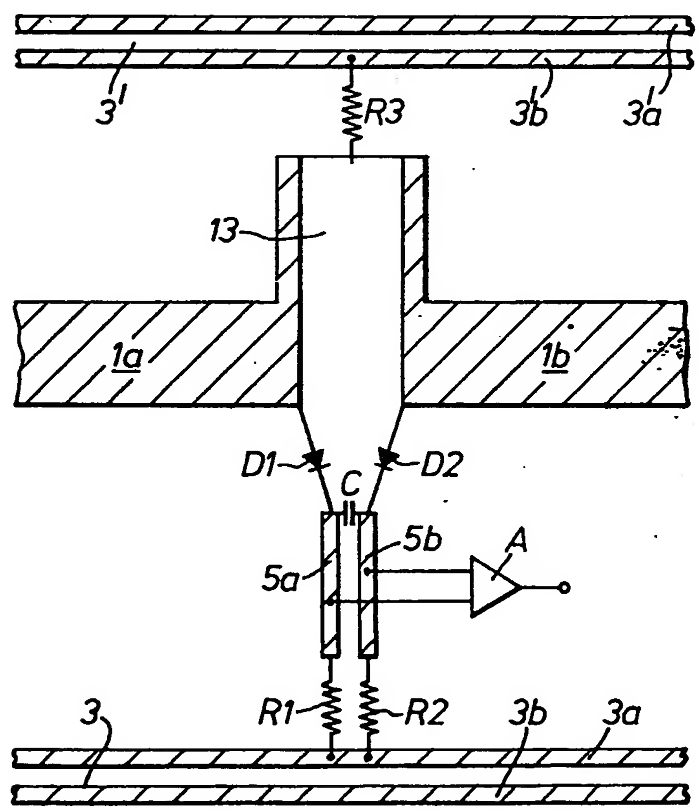

3'
R3
3b
3a
13
1a
1b
D1
C
D2
5b
A
5a
R1
R2
3
3b
3a

Fig.5.

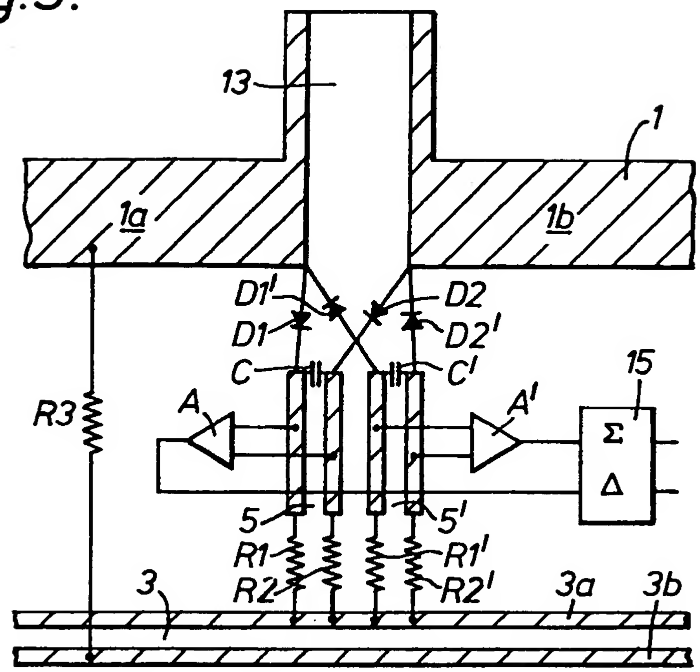

13
1
1a
1b
D1'
D2
D1
D2'
C
C'
15
A
A'
R3
Σ
Δ
5
5'
R1
R1'
R2
R2'
3
3a
3b

Fig.6.

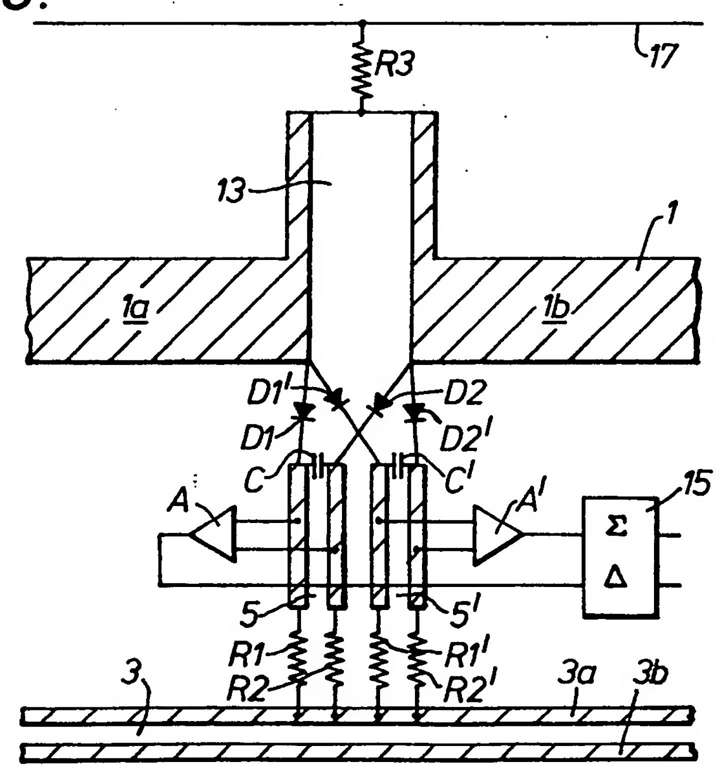

R3
17
13
1
1a
1b
D1'
D2
D1
D2'
C
C'
A
A'
15
Σ
Δ
5
5'
R1
R1'
R2
R2'
3
3a
3b

Fig.7.

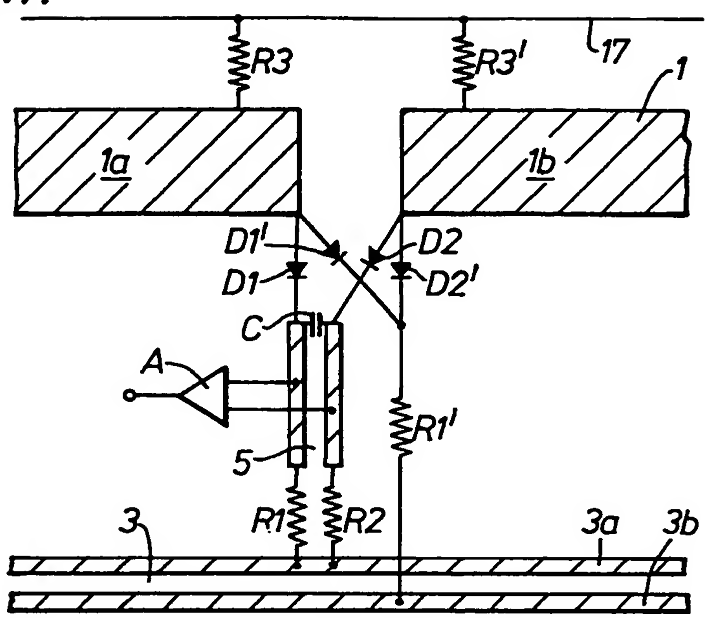

R3
R3'
17
1
1a
1b
D1'
D2
D1
D2'
C
A
R1'
5
R1
R2
3
3a
3b

Fig.8.

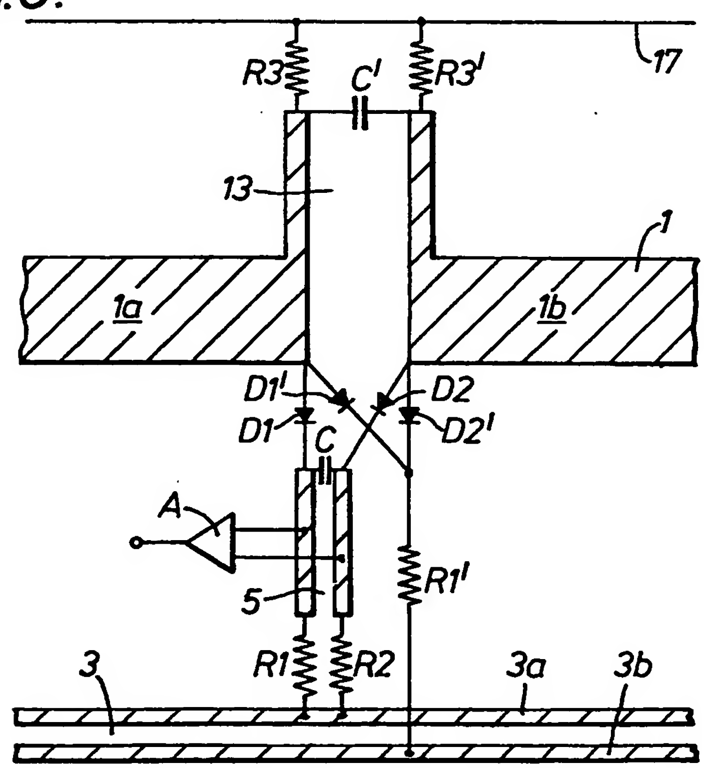

17
R3
C'
R3'
13
1
1a
1b
D1'
D2
D1
C
D2'
A
R1'
5
R1
R2
3
3a
3b

Fig. 9.

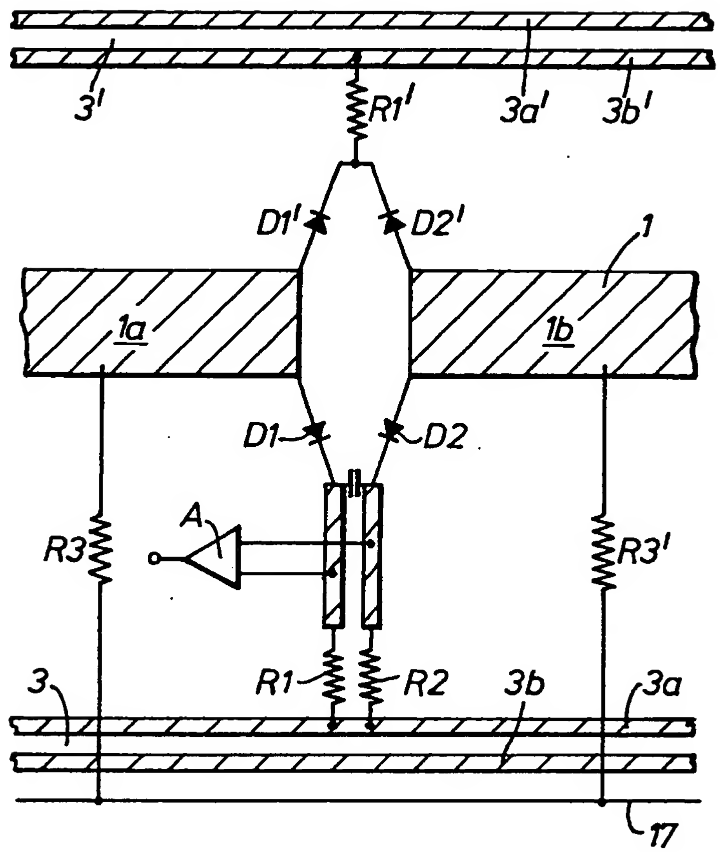

3'
R1'
3a'
3b'
D1'
D2'
1
1a
1b
D1
D2
A
R3
R3'
R1
R2
3
3b
3a
17

Fig. 11.

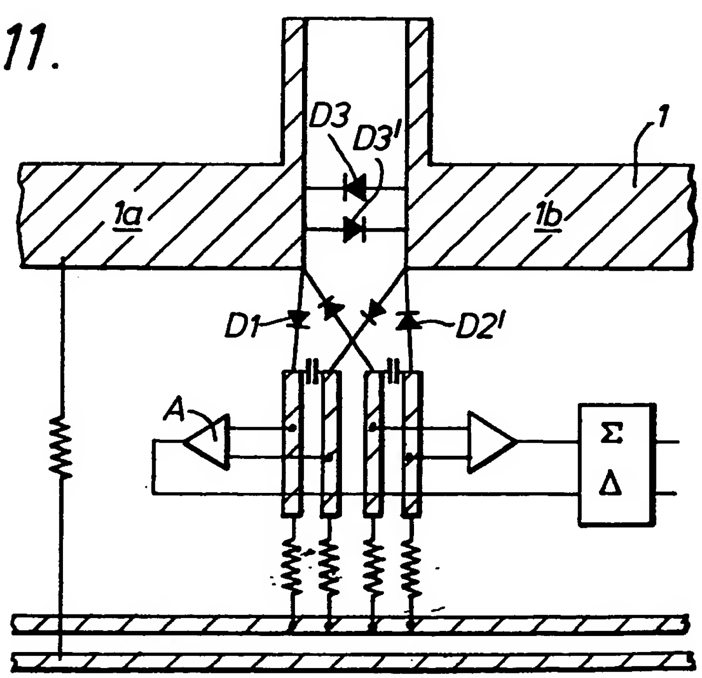

D3
D3'
1
1a
1b
D1
D2'
A
Σ
Δ

Fig.10.

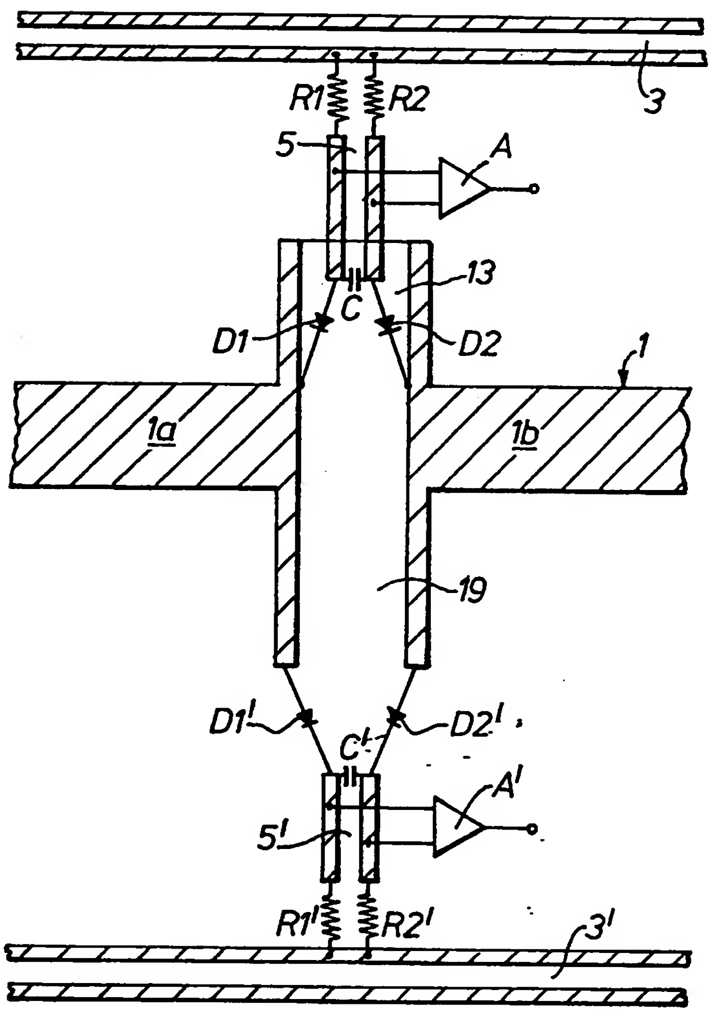


Fig. 14.

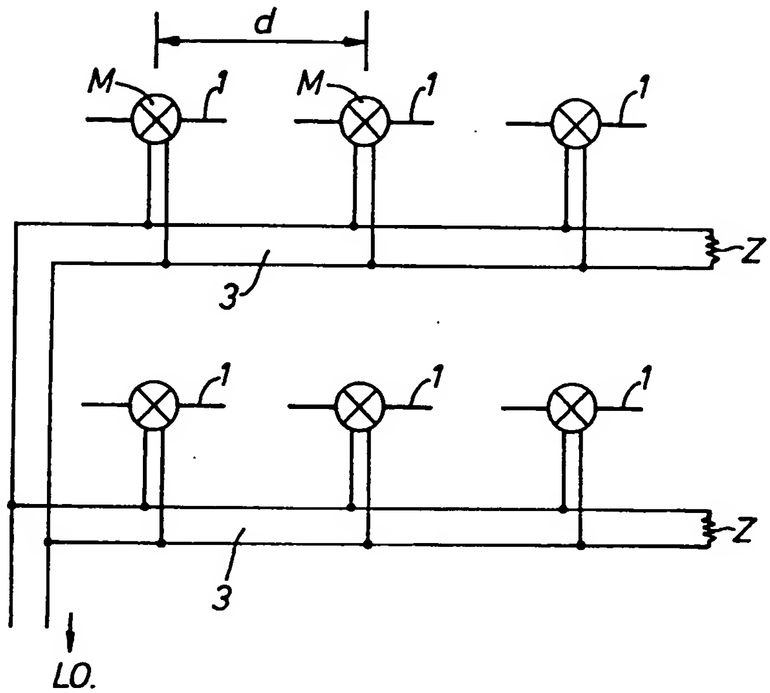


Fig. 12.

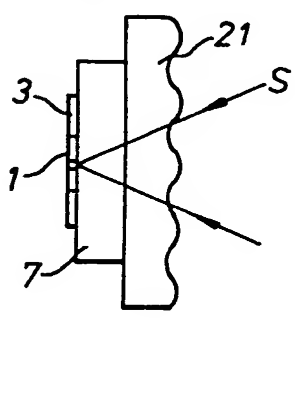


Fig. 13.

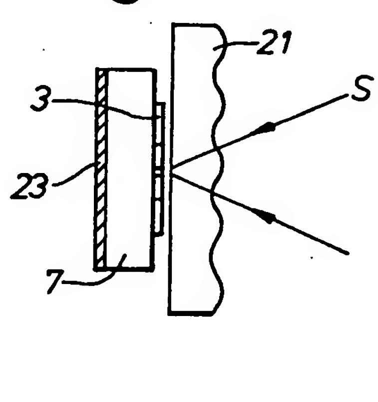


Fig. 15.

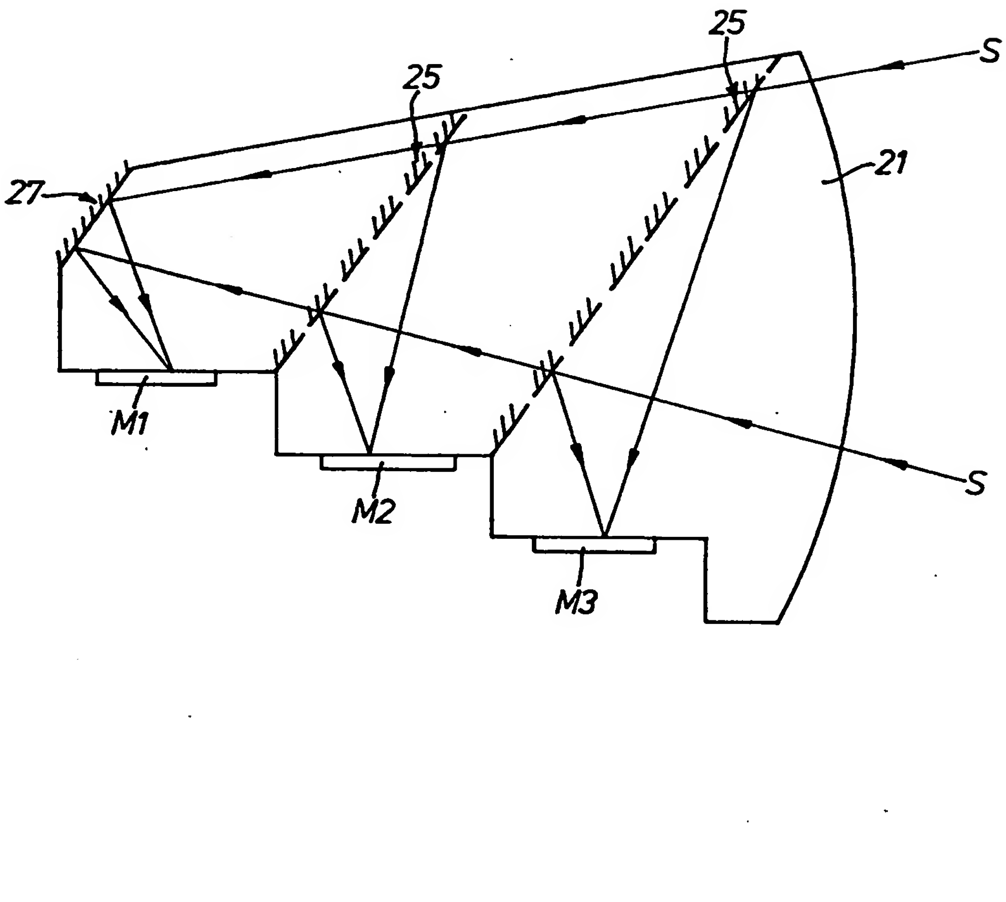
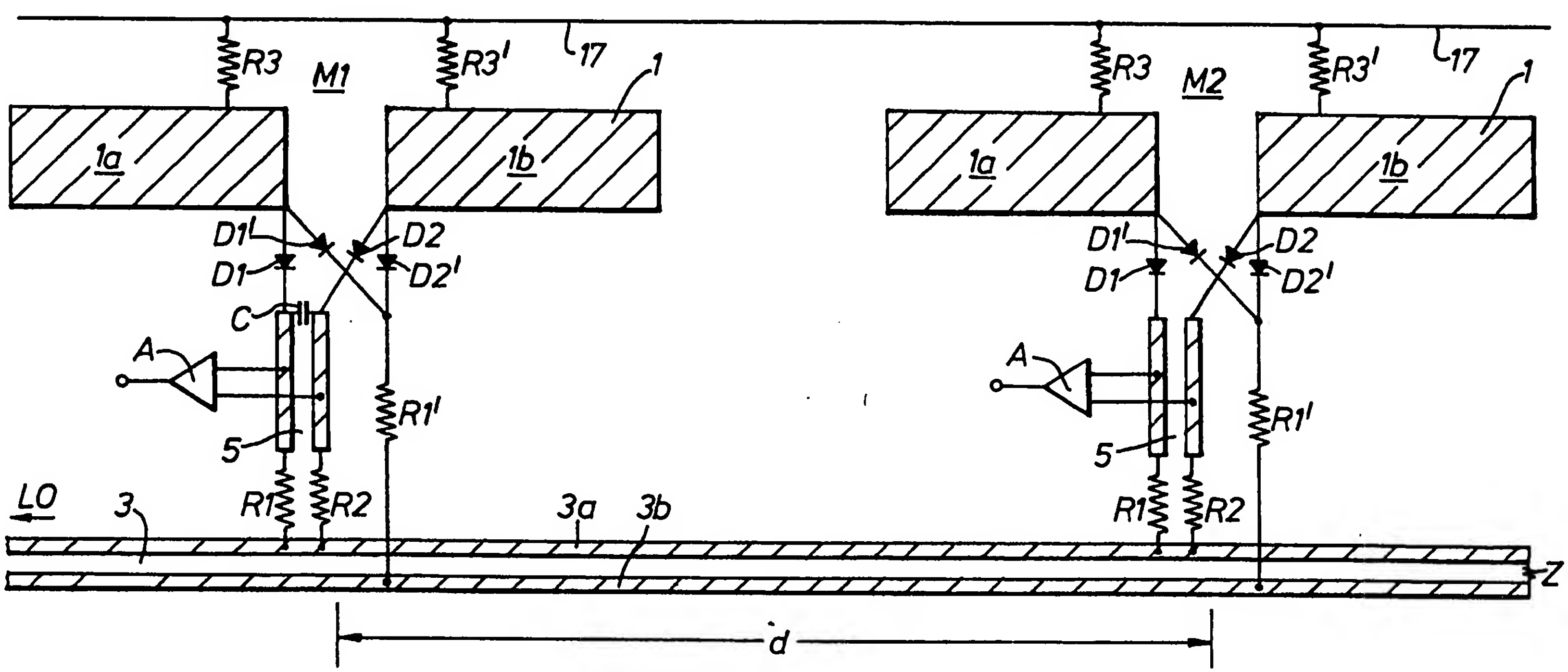


Fig. 16.



R3
M1
R3'
17
1
1a
1b
D1'
D2
D1
D2'
C
A
R1'
5
LO
3
R1
R2
3a
3b
R3
M2
R3'
17
1
1a
1b
D1'
D2
D1
D2'
A
R1'
5
R1
R2
Z
d

Harmonic Mixer and Circuit

TECHNICAL FIELD

This invention concerns harmonic mixers, particularly diode mixers for application at millimetre or centimetre band.

In a high frequency signal receiver it is usual to include a mixer at the front end of the receiver so that signal frequency may be reduced and subsequent signal processing may be performed at a lower and more manageable frequency. The mixer serves to mix received signal with a reference signal to develop a reduced frequency signal, a signal of frequency f_I that is the difference or harmonic difference of the frequencies f_S, f_R of the received signal and the reference signal:-

$$f_I = |f_S - nf_R|; \qquad \text{integer } n$$

In practice a series of harmonic difference signals is developed, ie for different harmonics n and, one of these signals, the signal at one chosen frequency, is extracted using a narrow band amplifier.

BACKGROUND ART

In a typical centimetre band receiver, high frequency signal is radiatively coupled to an aerial collecting dish and relayed to a micro-circuit mixer -eg a diode ring - by means of a waveguide. This micro-circuit usually consists of a dielectric support plate having patterned conductors and bonded semiconductor mixer components - eg diodes - on one surface and may also be metallised over all or part of the other surface. The positioning of these components is extremely critical. The micro-circuit is usually mounted in the waveguide cavity or else is connected to the waveguide by a specially designed transition. The positioning of this circuit relative to the waveguide is also critical.

The accurate positioning of the components and the positioning of the microcircuit are demanding mechanical tasks and are largely responsible for the relatively high production cost of these conventional receivers. These receivers are difficult to set up, fragile and expensive.

Mention is here made of UK Patent Application No 8206114, the content of which is imported herein by way of reference. Various mixers - eg balanced mixers and dual-balanced mixers - are disclosed therein. These mixers are of compact structure and each includes an antenna as an integrated part. Essentially each comprises a pair of crossed dipoles mounted on, or in very close proximity to, a high dielectric support body, and incorporates a mixer diode ring connected between the constituent limbs of the dipoles. When used, input signal and reference signal are each radiatively coupled to a different one of the two dipoles, each of which is designed to be resonant. The frequencies of input radiation and reference are similar.

DISCLOSURE OF THE INVENTION

The present invention provides a harmonic mixer and circuit that is both mechanically rugged and compact.

According to the invention there is provided a harmonic mixer and circuit comprising:-

a planar dipole antenna mounted upon a high resistivity body, and having connected between the constituent limbs of the dipole antenna, a mixer, comprised of at least one diode, matched in impedance to the radiation impedance of the antenna;
connective links connected to the mixer;
a reference signal source connected to the mixer by means of the connective links; and,

a narrow band amplifier connected to the mixer, responsive to mixed signals developed in the mixer, for extracting at least one signal at a frequency the difference between the frequency of incident signal radiation and an harmonic of the reference signal.

This mixer and circuit may be used to compare the phase of a high frequency signal with that of a stable reference signal of comparatively low frequency (eg a frequency a factor between four and thirty times lower than the signal frequency, would be typical). It may be used in radar applications to compare the phase of a local oscillator with a low frequency reference signal. It may also be used in frequency synthesisers.

Since the mixer is incorporated with the antenna, the circuit is of compact construction and the problems of positioning and mounting, referred to above, are obviated.

A simple mixer circuit including only one diode may be used for harmonic mixing. However, more complex circuits employing two or four diodes in balanced configuration offer advantages in practical systems, namely:-

a To minimise the amplitude of reference signal appearing across the amplifier. This makes it easier to identify the IF output and indirectly improves receiver sensitivity. It also reduces the influence of reference signal amplitude noise on the IF output.

b To separate the IF output signals corresponding to odd and even reference signal harmonics. This has advantage where measurement of a signal frequency close to $(n+\frac{1}{2})f_R$ is required.

c To separate upper and lower sideband signals.

The compact design of the mixer circuits, as aforesaid, makes such circuits suitable for array and multiple array assembly.

The mixer diodes may be discrete components bonded to the limbs of the antenna. In preference, however, the antenna may be supported upon a semiconductor body, and the mixer diodes, as also the amplifier, integrated in the structure of this body. This semiconductor body may be used as the high dielectric constant body, to serve to couple signal radiation to the antenna. It may instead be formed as an integral part of the high dielectric constant body. Alternatively a semiconductor body and a higher dielectric constant body may be arranged on opposite sides of the antenna, the semiconductor body serving to integrate the mixer diodes, and the dielectric body serving to couple signal radiation to the antenna.

BRIEF INTRODUCTION OF THE DRAWINGS

In the drawings accompanying this specification:-

Figure 1 is a drawing, part in plan and part schematic, of a single diode harmonic mixer and circuit;

Figure 2 is a plan drawing showing detail of a monolithic implementation of part of the circuit shown in Figure 1 above;

Figures 3 & 4 respectively, show in part plan and schematic, alternative two-diode harmonic mixer circuit variants;

Figures 5 to 10 show in part plan and schematic, a number of four-diode ring harmonic mixer circuit variants;

Figure 11 is a drawing, part in plan and part schematic, of a four-diode ring harmonic mixer circuit including overload protection diodes;

Figures 12 & 13 show in cross-section two different mounting arrangements for a mixer circuit of monolithic construction;

Figure 14 is a schematic circuit diagram for an array of harmonic mixer elements;

Figure 15 shows in illustrative cross-section a multiple array lens combination; and

Figure 16 shows in part plan and schematic, a twin-receiver array arranged to make instantaneous frequency measurement.

DESCRIPTION OF EMBODIMENTS

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawings.

Various forms of harmonic mixer circuit are illustrated in figures 1 to 11. These range from a simple single-diode mixer circuit assembly, as shown in figure 1, to more complex and preferred variants that include two-diode component mixers (see figures 3 & 4) and four-diode ring mixers (see figures 5 to 11).

The simple single-diode mixer circuit shown in Figure 1 is comprised of: a single-diode mixer element D; an antenna 1, for providing radiative coupling between an external signal radiation field and the mixer D; a local oscillator signal feed consisting of a feed transmission line 3, a short length of connective transmission line 5, and resistive connections R1 and R2, for providing direct conductive coupling between a local oscillator LO and the mixer D; and an intermediate frequency (IF) amplifier A connected to the mixer D, for extracting one of the mixed signal products, a signal having a frequency "f_I" given by the difference in frequency of the external signal "f_S" and a close harmonic "n" of the local oscillator reference signal "f_R":-

$$f_I = |f_S - nf_R|$$

The antenna 1 and the transmission lines 3 and 5 have been formed from common metallisation, a layer of metal deposited upon the surface of a supporting substrate 7 of high-resistivity material, either an insulating dielectric or a semiconductor. The antenna 1, a flat planar dipole is comprised of two limbs 1a, 1b spaced by a narrow gap across which the mixer diode D extends. The length of the dipole is chosen so that the antenna 1 is resonant at external signal RF frequency, or, if it is to be used to cover a range of external frequencies, it is designed to be resonant at a frequency within or close to the required band and usually near the low frequency end of this band. It is thus approximately one-half of a signal wavelength long, a wavelength dependent upon the properties of the supporting medium. The connective transmission line 5 is formed of a pair of planar conductors 5a and 5b; these extend orthogonally each from one of the dipole limbs 1a and 1b, respectively. The feed transmission line 3 is likewise comprised of a pair of flat parallel conductors 3a and 3b. The line pair 3 is narrow to ensure that propagation of the reference signal is confined to a well defined TEM mode, to avoid spurious coupling with the antenna 1.

The gap between the two conductors 3a, 3b, is usually chosen small compared with the width of each conductor 3a, 3b so that the line impedance presented is low. The resistive connections R1 and R2 provide connection between the conductors 5a, 5b of the connective transmission line 5 and the conductors 3a, 3b of the feed transmission line 3, respectively. The feed transmission line 3, the resistive connections R1 and R2, and the connective transmission line 5 thus provide a direct conductive path between the local oscillator LO and the mixer diode D. They also serve to carry dc bias current to and from the diode D. The effective length of the connective transmission line 5, together with its load termination, are chosen to avoid undue RF loading across the antenna 1. A capacitative load, a capacitor C is thus connected across the conductor pair 5a and 5b at a distance one quarter wavelength or less from the antenna 1. The effective RF impedance that this transmission line 5 presents across the diode D in the antenna path is thus either open circuit (for one quarter wavelength) or inductive (for less than quarter wavelength). In order to optimise mixer efficiency, it is usual to choose this impedance to be inductive, an inductance resonant with the diode capacitance at signal or signal centre band RF frequency. The length of connective transmission line 5 between the antenna 1 and the capacitor termination C is thus normally chosen to be between one-sixteenth and one-quarter wavelength in transmission mode. The inputs to the IF amplifier A are connected across the capacitor C, one input connected to each line conductor 5a and 5b, respectively. The capacitor C, which has low impedance at RF signal frequency, is chosen so that its impedance at DC and at IF is in comparison relatively high.

The mixer diode D, is a Schottky-barrier device. Other forms of majority carrier diode capable of developing significant harmonic content at RF however, would be suitable. It may be incorporated, as may the other components - the resistive connections R1, R2 and the amplifier A - as a hybrid component bonded in position. However the

compact structure of the mixer circuit assembly lends itself to monolithic integrated construction. Provided the supporting substrate 7 is of semiconductor material, these components therefore may be formed as integrated parts of the underlying substrate material.

The terminal part of the connective transmission line 5 is shown in figure 2. It has been formed with the amplifier A constructed as a component integral with the semiconductor material of the supporting substrate 7 and located beneath the metal of the connective transmission line 5. The amplifier A may be made in more than one part, as shown in figure 2, and in this case the parts of amplifier A may be connected electrically by one or more conducting elements under the transmission line parts 5a, 5b, 5c and isolated at low frequency from the transmission line 5 by an insulating layer. The capacitor C is formed of one part of one of the line conductors 5b, a dielectric overlay 9, and an extended part 5c of the other line conductor 5a which is electrically continuous with a tap metal overlay 11 which forms one plate of the capacitor C, above the underlying conductor 5b which forms the other plate.

It is a drawback of this simple construction of mixer circuit (Figure 1) that reference signal is applied directly across the IF amplifier A. The design of amplifier needed for effective LO signal and IF signal separation is accordingly demanding. This drawback may be obviated in balanced mixer circuit configurations; circuits including mixers having two or more diode components, examples of which are described below.

A two-diode mixer circuit is shown in figure 3. Here the single diode D has been replaced by a pair of diodes D1 and D2. These diodes are arranged back-to-back in series across the gap between the two limbs 1a and 1b of the antenna 1, and are joined to each side of a capacitor C at the near-end of a detached connective transmission line 5. As in the previous example, the design of capacitor C is

chosen so that it provides low impedance at signal RF whilst it presents relatively high impedance at IF and DC. The resistive connections R1 and R2 are arranged to provide connection between one of the feed transmission-line electrodes 3a and each of the connective transmission line electrodes 5a and 5b. The antenna 1 is co-extensive with a short length of shorted transmission line 13 which bridges the gap and extends orthogonally from the two dipole limbs 1a and 1b. This short length of transmission line 13 - typically, between one sixteenth and one quarter wavelength long - serves as an inductive stub and is designed with inductive RF reactance either greater than or matched equal to the capacitative RF reactance of the diode-capacitor combination D1-C-D2. The shorting impedance at the end of this stub 13 is of low resistance and provides DC continuity between the two limbs 1a and 1b of the antenna 1. The DC bias and LO reference circuit is completed by a resistive connection R3 which extends between one limb 1a of the antenna 1 and the other conductor 3b of the feed transmission line 3. The resistive connection R3 must be carefully chosen, for it should not provide a significant RF current path between the antenna 1 and the feed transmission line 3 which would otherwise off-set resonance, distort the antenna performance and decrease efficient operation. This connection R3 can be provided using a high resistivity conductive link, or alternatively it can be of a patterned resistive metal structure where the resistive material is subdivided into a number of parallel paths normal to the antenna. The latter structure is designed to provide high resistance at RF whilst allowing for modest resistance at DC. Further details of this structure are disclosed in UK Patent Application GB 82 13349, quoted here for purposes of reference.

A variant of this two-diode mixer circuit is shown in Figure 4. Here a second feed transmission line 3' is provided, a line connected, in parallel with the first feed transmission line 3, to the local oscillator LO and to the DC source. The DC bias and LO reference circuit continuity is again provided by a resistive connection R3, but in this case the connection is made between one conductor 3b' of the

second feed transmission line 3' and the stub 13. The stringent design considerations for this connection, discussed above, are obviated.

The mixer circuits shown in figures 3 and 4 respond to signal mixing products with odd and even LO harmonics. This can create a problem where the signal frequency f_S is close to $(n+\frac{1}{2})f_R$. The mixing products with nf_R and with $(n+1)f_R$ are then nearly equal in frequency and hard to distinguish. Ultimately this prevents discrimination of signals of frequency slightly below $(n+\frac{1}{2})f_R$ from those of frequency slightly above.

Mixer circuits with ability to separate mixing products with odd and even harmonics are described below.

The circuit shown in figure 5 is a derivative of the circuit already shown in figure 3. It is based on the fact that reversal of the diodes D1 and D2 reverses the sign of IF signals obtained by mixing with odd harmonics, but does not reverse the sign for even harmonics. In figure 5 the circuit thus includes a second pair of diodes D1' and D2' (arranged in reverse direction to the pair D1 and D2 first mentioned), a second capacitor C', a second connective transmission line 5', a second pair of resistive connections R1' and R2' providing connection between the second connective transmission line and one conductor 3a of the feed transmission line, and a second amplifier A'. The outputs of the two amplifiers A and A' are connected to the inputs of a sum-and-difference unit 5. The sum output of this unit 15 gives the product formed by mixing the signal with even harmonics of the reference signal, whilst the difference output gives the product formed with the odd harmonics. Precise separation of even and odd intermodulation products depends upon perfect matching of the diodes and resistors, the shorted transmission line 13 acting as an ideal short circuit at IF and the amplifiers A and A' being matched. In practice the separation will be imperfect, but the strongest signals at the sum

and difference outputs may be used in subsequent signal processing, for example, to determine the signal frequency.

A variant of this circuit is shown in figure 6. Here the diodes D1 to D2' are arranged all in the same direction but the resistor pairs R1, R2 and R1', R2' are connected to different conductors 3a and 3b respectively of the feed transmission line 3. Connection between the antenna 1 and the feed line 3 is avoided; the DC bias circuit is completed by a resistive connection R3 extending between the stub 13 and a DC bias line 17.

For some applications response to either odd or even LO harmonic mixing will be sufficient. The circuit shown in figure 4, for example, can to this end be modified by replacing each diode D1 and D2 by a back-to-back pair. Operation, in this case, does not require application of DC bias. This circuit is responsive to even harmonic mixing products only.

The circuit shown in figure 7 is designed to have a response to odd harmonic intermodulation products only. Here the two diodes D1 and D2 are connected to a connective transmission line 5, a capacitor C, an amplifier A, and resistive connections R1 and R2 to one of the conductors 3a of a feed line 3. Another pair of diodes D1' and D2' is connected to the other conductor 3b of this feed line 3 by a resistive connection R1'. Extra resistors R3 and R3' are added to provide DC bias current for the four diodes D1 to D2'. These resistors R3, R3' are connected between a DC bias line 17 and the dipole limbs 1a and 1b, respectively, of the antenna 1. As discussed in the context of figure 3, all resistive connections to the dipole metal must be carefully designed to obviate undue RF loading of the antenna 1. In the variant of this circuit shown in figure 8, a matching, capacitatively terminated stub 13, is included, and the resistors R3, R3' connected between this stub 13 and the bias line 17.

In these two circuits, figures 7 and 8, mixing products resulting from even LO harmonics cancel at the amplifier input as long as the LO drive to the first pair of diodes D1 and D2 is the same as that to the second pair of diodes D1' and D2'. This condition can be achieved if the resistors R3 and R3' have a much higher resistance than resistors R1, R2 and R1'.

In the mixer circuit shown in figure 9, a variant of the circuit of figure 7, the resistor R1' is connected between the second pair of diodes D1' and D2' and one of the conductors 3b' of a second feed transmission line. 3'.

Figure 10 shows an example of a mixer circuit which provides two amplified outputs, each taken from one pair of mixer-diodes D1, D2 and D1', D2' respectively. In this example the two pairs of diodes D1, D2 and D1', D2' are spaced by a length of transmission line 19. This serves as a delay line and provides a phase delay ϕ, for example a phase delay of $\pi/2$ by design, between the RF signal applied to the lower diode pair D1', D2' and that applied to the upper diode pair D1, D2. The LO drives are in phase. There is therefore a phase shift between the outputs of $\pm\ \phi$ according to whether the signal frequency is above or below the harmonic frequency nf_R. The sign of this phase shift may thereafter be used to determine the IF sideband sign:-

$$f_S = nf_R \pm f_I \quad .$$

In certain practical applications, for example in radar interception, the circuits may become exposed to very high level RF radiation. In these circumstances circuit protection is needed. One precaution that may be taken is to include limiter diodes, diodes which can switch rapidly and cope with the high RF currents induced in the mixer-receiver. An illustration of this is shown in figure 11 where a pair of parallel limiter diodes D3, D3' have been added to the circuit of figure 5. This diode pair D3, D3' has been inserted across

the gap of the antenna 1 between the two dipole limbs 1a and 1b where it can best serve to shunt high power RF signal thereby by-passing the mixer diodes D1 to D2'. This diode pair D3, D3' can be provided by two reversed Schottky diodes or by a Schottky diode and PIN diode combination.

Figures 12 and 13 show two principal mounting arrangements for mixer circuits of the kind described above:-

In figure 12 the antenna 1 and transmission lines 3, 5 metal is deposited on the surface of a semiconductor substrate 7. This substrate 7 is bonded on to the back surface of an insulating dielectric block 21. The semiconductor and dielectric materials are preferably chosen with approximately similar dielectric constants to optimise the proportion of signal radiation S transmitted through the dielectric and semiconductor mediums 21 and 7 to the antenna 1. The dielectric block 21 may be shaped to serve as a lens, or may be used as part of a compound lens, to concentrate or focus radiation on to the antenna 1.

In figure 13 the semiconductor substrate 7 is in inverted position, the metal surface components 3 and 7 being sandwiched between the semiconductor substrate 7 and the dielectric block 21. These metal components 3 and 7 if not in touching contact with the block 21 are maintained sufficiently close to its surface that any air in the space between has no appreciable effect upon the antenna-radiation field coupling and the behaviour is for all practical purposes no different from an antenna at a semiconductor-dielectric interface. In contrast to the foregoing example, the dielectric constant of the dielectric medium 21 is chosen to be somewhat greater than that of the semiconductor medium 7 so that the antenna couples predominantly to radiation from the dielectric side of the assembly. A layer 23 of screening metal or of protective dielectric may be included over the back surface of the substrate 7.

HARMONIC MIXER CIRCUIT APPLICATIONS

Each mixer circuit, described above, may be used alone as a receiver. Since the mixer circuit is of compact structure it may be utilised, in combination with two or more other like circuits, in the form of one- and two-dimensional arrays. Furthermore, two or more arrays can be combined in one complex receiver system for the more demanding of radar applications. A few applications are described in the text that follows below:-

1. Single receiver application:-

In some radar systems - for example doppler radar systems, it is necessary to measure the phase of a high frequency local oscillator relative to a reference source of high phase stability. The latter is usually at a comparatively low frequency, a typical frequency being in the range 50 MHz to 1 GHz. A small fraction of the high frequency local oscillator power - typically one microwatt - is radiatively coupled by the signal antenna 1 of an harmonic mixer. The reference signal for this mixer is provided by a lower frequency high stability source LO. The IF output of the mixer is amplified and its phase $_{IF}$ is measured. This measurement may be performed, for example, using a phase-sensitive detector and another stable reference source, albeit one whose frequency is close to that of the IF output signal. The phase of the high frequency local oscillator is then given by:-

$$\phi(t) = n\omega t + \phi_{IF}(t)$$

where $\phi_{IF}(t)$ is the phase of the IF signal, ω is the LO frequency for the harmonic mixer, n is the harmonic number, and t is the time variable. For many applications, knowledge of the values of the harmonic number n and the reference frequency ω, is not requisite, provided that they remain constant.

In United Kingdom Patent Application GB 82 06114 there are described a number of integrated circuit fundamental frequency mixers. Each mixer is comprised of a pair of crossed dipoles having at or near its centre a ring mixer, the diodes of which are embodied in underlying semiconductor substrate material. The harmonic mixer described above may be used to monitor local oscillator phase for such a fundamental frequency mixer circuit or array of such circuits. It is convenient then to incorporate the harmonic mixer using a common semiconductor substrate 7 at a position adjacent either the one fundamental frequency mixer, or the array of fundamental frequency mixers.

The measurement of phase, determined as above, may be used to compute phase corrections which may be added or subtracted, as found appropriate, during subsequent array signals processing, and this correction may be performed digitally. The phase correction may alternatively be made by multiplying an IF output signal from the fundamental mixer receivers with a signal obtained by limiting the IF output from the harmonic mixer. This technique may be used to assist evaluation of the doppler spectrum of a target under conditions where the primary high frequency local oscillator source itself has poor phase stability.

2. Array applications:-

As already stated, a number of harmonic mixer circuits may be combined to form a receiver array. A general layout for such an array is illustrated in figure 14. The harmonic mixers M, the antennae 1 of which are shown, are arranged in rows, and all use a common high resistivity substrate 7. Each row is served by a common feed transmission line 3. Each transmission line 3 is connected in parallel to a common local oscillator LO, and is terminated by an appropriate impedance Z. Each impedance Z may be a resistive load matched to the characteristic impedance of the transmission line 3, and is designed to absorb reference signal. This minimises reference signal reflection from the ends of the lines 3, and consequently makes it easier to

control the relative phase of the reference signal applied to each receiver. The phase of the reference signal will vary from mixer to mixer, because there is a phase shift kd introduced between each mixer M, where "k" is the propagation constant of the transmission line 3 and "d" the separation of the mixers.

In an array receiver it is usually desirable to ensure that the amplitude of the reference signal is the same at each mixer M. This may in practice be achieved where the connective resistors R1, R2; R1', R2' of the mixer M are much larger than the impedance of the transmission line 3 and of the matched terminations Z. It follows in this case that the reference signal power taken by each mixer M is then small compared with the LO drive applied to each transmission line 3.

An alternative method for making the amplitudes of the reference signal equal at the various mixers is to include in the circuit a buffer amplifier operating at reference frequency at each intersection of the transmission lines 3 and the reference signal circuit at each mixer. Each buffer amplifier is designed to provide a comparatively low loading to its input feed, ie the transmision line 3, so that the reference signals are only slightly attenuated as they propagate along the transmission lines.

An array of harmonic mixers M at the focal plane of a lens 21 may be used as a broad bandwidth receiver. Because the receiver antennae 1 lie in the focal plane of the lens 21, each couples to a different beam direction. Thus a measurement of the amplitudes of the IF output signals from each mixer M may be used to estimate the direction of the incident wave and hence of its source. It is convenient for the receiver spacing to be approximately equal to the separation of Rayleigh spots on the lens focal surface. Amplitude monopulse may be used then to refine this estimate of direction. It is not strictly necessary for the receiver array plane to coincide with the focal surface of the lens 21 since in principle the signals from different mixers M may be

weighted and combined so as to give the same outputs as would be obtained from an array in the focal surface. This latter approach may be usefully adopted where the focal surface is curved and the receiver array can only be fabricated in planar form.

An array plus lens may be used to detect and estimate the bearing of incident radiation over a band of frequencies limited by the bandwidth of the signal antennae 1. There are two difficulties which need to be overcome. Firstly, in order to recognise that a signal is present, the IF output from each mixer M needs to be amplified to such a level that it can be recognised by threshold detection. Where the input signals are weak, the gain of the IF amplifier A needs to be of order 60 dB, which is an inconveniently high value for the gain of stable amplifiers with bandwidths which are typically of order 500 MHz. It is more convenient to use a lower amplifier gain of, say, 30 dB, and test the output from each mixer amplifier A in sequence. The remaining gain may then be provided by an external boost amplifier. If then the array mixers M are addressed sequentially, the probability of a pulse of incident radiation being detected is unity only if the pulse duration, T_P, exceeds the time T_S taken to examine all the array outputs. For shorter pulse duration T_P, the detection probability falls roughly in the ratio T_P/T_S. It is useful to reduce the address time T_S by extracting more than one IF output at a time. It is useful to split the incident radiation so that it falls on more than one array. The scanning of the arrays is interlaced so that the effective T_S is reduced and the probability of detecting a short pulse of incident radiation is increased.

Secondly, in order to carry out threshold detection conveniently it is necessary to sample the IF signal for a period of at least one cycle at IF frequency. Since the time allowed for sampling the IF signal is limited, the minimum IF frequency would normally exceed a lower limit of about 50 MHz (which corresponds to a minimum sample time of 20 ns). Thus the receiver array cannot readily respond to signals

closer than this figure (typically 50 MHz) to the reference harmonic. In order to eliminate such frequency blind spots it is convenient to use a combination of two or more arrays with each array supplied with a different reference frequency. A reasonable difference in reference frequency Δf_R is given by

$$n \Delta f_R = k f_{min}$$

where n is a typical harmonic number at which the receiver is operating, f_{min} is the minimum detectable IF frequency and k is a constant rather greater than 2. If this equation is satisfied, the same harmonic n for the two different LO frequencies leads to a separation of IF frequency of $n \Delta f_R$ and at least one of these must exceed f_{min} in magnitude.

It therefore follows that a receiver designed to intercept incident radar (or other) pulses would use two or more arrays. This is accomplished by splitting the incident radiation using one or more mirrors with one array in the focal plane associated with each reflected beam. This principle may be extended to include polarisation sensitive detection (using a polarisation selective mirror) and to increase the overall bandwidth by using arrays with increasing antenna lengths and receiver element spacings (proportional to wavelength). In the latter case sensitivity is improved if wavelength selective mirrors, eg multilayer dielectric mirrors, are used.

A multiple array assembly is illustrated in figure 15. As shown, a number of mixer circuits M1, M2 and M3 are located each at one of the focal planes of a dielectric compound lens 21. The body of this lens 21 incorporates a plurality of inclined mirrors, two of these mirrors 25 are partially reflecting, and one 27 is totally reflecting.

Frequency Measurement

As well as detecting the presence of incident radiation and estimating the direction of the incident beam it is useful to be able to estimate the frequency of the incident radiation. This may be done in a variety of ways using one or more receiver arrays. The methods using two or more arrays are easier and are therefore more suitable for multi-array sensors which also offer the elimination of blind frequencies, broader overall bandwidth, polarisation sensing and an increased probability of detecting a short pulse.

All the methods include a measurement of the IF frequency f_I, a determination of the harmonic number n, and a determination of whether the signal frequency is above or below the n'th harmonic of the local oscillator. The signal frequency is then calculated from the equation

$$f_S = nf_R \pm f_I \quad .$$

One method for measuring the IF frequency is to convert the IF signal to a square wave using a limiter and either to measure the time elapsed during a predetermined number of cycles or to count the number of cycles in a predetermined time.

The harmonic number n and whether the signal frequency is above or below nf_R, which we denote by the boolean variable b, are determined by comparing the IF signals from at least two different receiver elements. These receiver elements may be in the same array or in different arrays in the same lens system. It is necessary for the IF signals to be strong compared with noise and this means that the incoming radiation must be coupled strongly to the antennas of all the mixers that are to be used for the IF signal comparison. Where these receiver elements are on the same array it is desirable for the spacing between them to be smaller than the radius of the illuminated spot on the array plane caused by a plane wave incident on the lens. Where this condition

applies, the radiation will always couple strongly to at least two receiver elements, neither of which is close to the first amplitude minimum of the radiation field in the array plane. For an array in the focal plane of a lens the radius of the Rayleigh spot is approximately 0.65 λ_s and a typical antenna length is 0.45 λ_s, where λ_s is the surface wavelength $\lambda_s = \lambda_o/\bar{n}$, where $\bar{n} = \sqrt{(\epsilon_1+\epsilon_2)/2}$.

To illustrate how instantaneous frequency measurement may be performed, a two-element mixer array is shown in figure 16. This array comprises two mixer circuits M1 and M2 spaced a distance d apart. The circuits illustrated are those previously described with reference to figure 7 above. The material of the common substrate 7 is of high resistivity. The attenuative loss in this medium, therefore, is small. This loss is given approximately by the ratio (Z'/ρ_s), where Z' is the characteristic impedance for the propagation of radiation through the substrate 7, and ρ_s the sheet resistivity. For example, using as substrate material, the semiconductor material silicon ($Z' \simeq 100\ \Omega$) with a substrate 7 of typical thickness 400 μm, a maximum attenuation loss of 5% is found for a relatively high sheet resistivity of 100 Ω cm. The proximity of the antenna metal to a semiconductor body of finite conductivity leads to parasitic power absorbtion at signal frequency additional to this simple attenuation loss. This additional loss increases at lower frequencies, but is reduced in the case of the sandwiched antenna structure of figure 13, provided the dielectric constant of the dielectric body 21 is significantly higher than that of the semiconductor body 7. The arrangement of figure 13 is therefore preferable at lower microwave frequencies, typically below 20 GHz if the semiconductor body 7 is 100 ohm cm silicon.

The circuits M1, M2 shown in the drawing have been designed to respond to incident radiation of 10 GHz frequency or thereabouts. The length of each antenna 1 has been chosen so that each antenna 1 is half-wave resonant at a centre frequency of 10 GHz. This length is governed by the antenna geometry, the dielectric constant ϵ of the

substrate 7, and the dielectric constant ϵ' of the ambient medium, air ($\epsilon' = 1$). For silicon material ($\epsilon = 11.7$), an antenna length of 6 mm approx is resonant at 10 GHz, and an antenna having a length-to-width aspect ratio 10 to 1, the resonance extends from about 0.75 to 1.1 times resonant frequency, ie from 7.5 to 11.0 GHz. A reference signal of frequency $f_R \simeq 500$ MHz is applied, and the amplifiers A are chosen for extraction of IF signal around the twentieth harmonic or thereabouts, ie the harmonic number $n \simeq 20$. The array M1, M2 is used in combination with a dielectric lens 21, a lens of alumina material and having a lens F-number of F/0.7. A mixer separation $d \sim 8$ mm is adequate to ensure coverage by both mixers M1 and M2.

The transmission line 3 inserts a phase difference ϕ between mixers M1, M2. For optimum performance it is arranged that this phase difference ϕ results in quadrature in the amplifier output signals, for one frequency in the band of interest. Should the phase difference required exceed the value kd, the transmission line 3 may be folded or meandered to increase electrical path length as required.

Suppose then that the reference signals at the two mixers M1 and M2 are $A \cos \omega_1 t$ and $A \cos (\omega_1 t + \phi)$ respectively, and the incoming radiated signal received at the two mixers varies with time as $\cos(n\omega_1 + \Delta\omega)t$. The mixed down output signals at the outputs of the amplifiers A then vary as $\cos(\Delta\omega t)$ and $\cos(\Delta\omega t - n\phi)$. The frequency of the mixed down signals is then measured. This is $\Delta\omega$, but this measurement alone does not distinguish an upper sideband frequency $n\omega_1 + \Delta\omega$ from a lower sideband frequency $n\omega_1 - \Delta\omega$. However, if the phases of the two mixed down signals are compared (eg by passing each signal through a limiter and measuring the time between the upward going edges of the limited signals) then the upper or lower sideband cases can be distinguished and the value of the harmonic number n found. If the phase of the mixed down signal from the second mixer M2 relative to that from the first mixer M1 is θ, then if θ is negative, the upper sideband (ie $\Delta\omega > 0$) case applies and $n = -\theta/\phi$. If θ is positive, the

lower sideband case ($\Delta\omega<0$) applies and $n = +\theta/\phi$. In both cases $n = |\theta|/\phi$. Thus the incoming frequency $n\omega_1 \pm \Delta\omega$ may be determined.

The alternative arrangement whereby the IF signals are compared from receivers in different arrays, eg as in Fig 15, has the advantage that receiver spacings similar to the Rayleigh spot radius, rather than less, are acceptable. It is convenient to position the arrays and the mirrors so that an incident plane wave with one focal spot on the (i,j)'th element of one array produces another focal spot on the (i,j)th element of the other array. The disadvantage of using two arrays rather than one is that more components are needed. However, since a broad band receiver designed to detect the presence of incoming radiation conveniently uses several arrays, there is little penalty in using two (or more) arrays for frequency measurement where this is required in the same system.

The harmonic number n and the boolean variable b are determined from the IF signals from two (or more) mixers in one of two ways. Where the reference frequencies for the receivers are different, the IF frequencies are tested for compatibility with various possible values of n and b. For general details of such techniques, the reader is referred to an article by C S Aitchison entitled "Low frequency sample provides pulse frequency measurement" appearing in Microwave Systems News (Feb 1983) pages 172-180. Alternatively, where the reference frequencies are the same a phase shift ϕ between the reference signals to the arrays is arranged, for example by including a delay line in the reference feed to one of the arrays. Comparison of the phases of the IF signals from corresponding receivers of the two arrays, then allows the harmonic number n and the boolean variable b to be determined as previously described.

CLAIMS

What I claim is:-

1. An harmonic mixer and circuit comprising:-

a planar dipole antenna mounted upon a high resistivity body, and having connected between the constituent limbs of the dipole antenna, a mixer, comprised of at least one diode, matched in impedance to the radiation impedance of the antenna;

connective links connected to the mixer;

a reference signal source connected to the mixer by means of the connective links; and,

a narrow band amplifier connected to the mixer, responsive to mixed signals developed in the mixer, for extracting at least one signal at a frequency the difference between the frequency of incident signal radiation and an harmonic of the reference signal.

2. A device as claimed in claim 1 wherein the body is of semiconductor material, each diode and the amplifier being components integrated within this body.

3. A device, as claimed in claim 2, including a body of insulating material, this material having a dielectric constant close in value to that of the semiconductor body material, the free surface of the semiconductor body being bonded to the insulating body.

4. A device as claimed in claim 2, including a body of insulating material, this material having a dielectric constant higher in value than that of the semiconductor material, the bodies being arranged closely adjacent to one another, the antenna lying therebetween.

5. A device, as claimed in any one of the preceding claims, including a dielectric lens integral therewith.

6. A device, as claimed in either claim 3 or 4 wherein the insulating body has the form of a dielectric lens or a component part of a composite dielectric lens.

7. A device as claimed in any one of the preceding claims wherein the mixer is comprised of at least two like diodes, these diodes being arranged in a balanced configuration.

8. A device as claimed in claim 7 wherein the mixer is comprised of two pairs of like diodes, the diodes being arranged in a balanced ring configuration.

9. A device, as claimed in claim 8, including a pair of matched amplifiers, one connected between each pair of diodes.

10. A device, as claimed in claim 9, including processing means, connected to the output of each amplifier, for providing signals, the sum and difference of signals presented at these outputs.

11. A device, as claimed in claim 8, including a delay line arranged in circuit between the two pairs of diodes, this line being formed of metal continuous with each limb of the antenna dipole, and extending orthogonally therefrom.

12. A device as claimed in any one of the preceding claims 7 to 11, including an inductive stub, this stub being formed of metal conductors continuous with each limb of the antenna dipole, extending orthogonally therefrom, and having a resistive termination, this stub serving as an impedance shunt across the mixer.

13. A device as claimed in any one of the preceding claims including a pair of limiter diodes, connected in parallel, and inserted between the limbs of the dipole antenna.

14. An harmonic mixer and circuit constructed, arranged and adapted to perform substantially as described hereinbefore with reference to and as shown in any one of figures 1 to 13 of the accompanying drawings.

15. A receiver comprising:-

a common supporting substrate of high resistivity material;
a plurality of receiver elements spaced apart and disposed upon the surface of this substrate, each element including a planar dipole antenna, a diode-mixer connected between the limbs of the dipole antenna, and at least one narrow band amplifier connected to the mixer;
a plurality of common conductors disposed upon the surface of the substrate, to feed reference signal, and to feed any d.c. bias current required, to the mixer elements; and,
connective links providing coupling between each element and the plurality of conductors.

16. A receiver as claimed in claim 15 wherein the substrate is of semiconductor material and the diode-mixers and amplifiers are components integrated within the body of this material.

17. A receiver as claimed in either claim 15 or 16 wherein the receiver elements are arranged in two dimensional array, conductors for each row being arranged as a transmission line, each transmission line being connected in parallel for connection to a common reference source.

18. A receiver as claimed in any one of the preceding claims 15 to 17 including a plurality of feed amplifiers, each providing coupling between a corresponding one of the receiver elements and the reference feed conductors.

19. A receiver, as claimed in any one of the preceding claims 15 to 18, including a dielectric lens integral therewith, the antennae being positioned at or near the focal surface of this lens.

20. A receiver assembly comprising in combination:-

a dielectric lens;
a plurality of inclined reflecting mirrors, at least one thereof being partially reflecting and incorporated within the body of the lens; and
a plurality of receivers, as claimed in any one of the preceding claims 15 to 19, each mounted adjacent to the lens, at or near a focal surface thereof, to receive signal radiation deflected by a corresponding one of the mirrors, and focussed by the lens.

21. An assembly, as claimed in claim 20, including a common reference source, and phase shifting means co-operative therewith, for arranging that reference signal of different phase is applied to each receiver.

22. An assembly, as claimed in claim 20, including reference sources for providing reference of different frequency for each receiver.

23. An assembly, as claimed in claim 20, wherein the antennae of different receivers, are of different lengths.

24. A direction sensitive interception receiver, comprising in combination: a dielectric lens; at least one array of receiver elements, each element including a planar dipole antenna, a diode mixer connected between the limbs of the dipole antenna, and at least one narrow band amplifier connected to the mixer; conductors and connections for connecting each mixer with a reference source, as also for any d.c. bias; a threshold detector, a measuring circuit responsive to the output of each amplifier, and computational means; arranged for calculation of the frequency, pulse duration, and direction of sensed radiation.

25. A receiver, or receiver assembly, constructed, arranged, and adapted to perform substantially as described hereinbefore with reference to and as shown in any one of figures 14 to 16 of the accompanying drawings.

tents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number 8318069.5

Relevant Technical fields

(i) UK Cl (Edition E) H1Q (QKA)

(ii) Int Cl (Edition -)

Search Examiner

H E GRIFFITHS

Databases (see over)

(i) UK Patent Office

(ii) -

Date of Search

24 NOVEMBER 1983

Documents considered relevant following a search in respect of claims 1, 15, 24 at least

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	GB 1488850 (RCA)	

Category	Identity of document and relevant passages	Relevant to claim(s.

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